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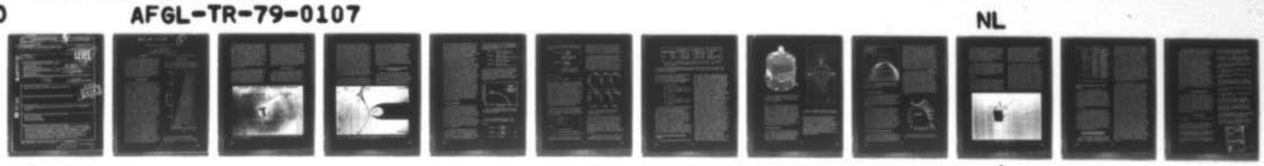

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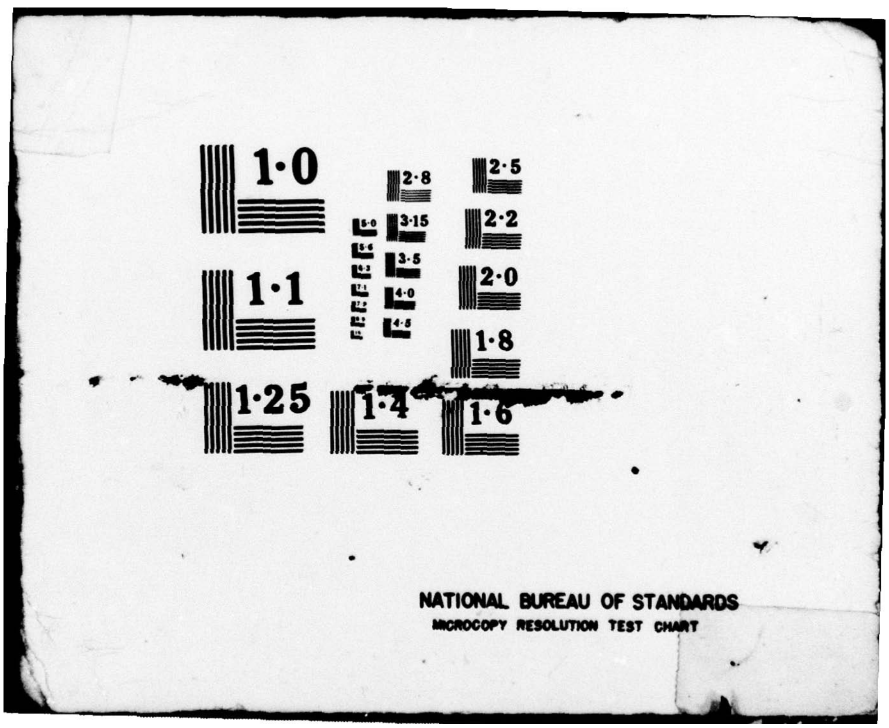
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SPACECRAFT CHARGING TECHNOLOGY

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SUMMARY

A summary of the problem of spacecraft charging by the ambient space plasma environment is presented. Some results of the Air Force/NASA spacecraft charging technology investigation are highlighted. Details of an Air Force/NASA spacecraft-environment interactions technology investigation are presented. This investigation will develop an environmental technology base for application to the development of next-generation large dimension, high power spacecraft.

INTRODUCTION

Many important Air Force systems -- for communications, for surveillance, for navigation -- are satellite-based, and most of these are in geosynchronous orbit for maximum efficiency. At the altitude of geosynchronous satellites (about 42,100 km or 6.6 earth radii), a satellite is far above the density variations of the sensible atmosphere, or the fluctuations of the ionosphere. Nevertheless, there are still physical processes and coupling mechanisms that involve the space radiation environment, space plasmas, and electric and magnetic fields in space that can interact with the satellite and disturb its operation. Geophysical researchers have already constructed first-order models of the plasmas, particles, and fields in space, and there is ongoing R&D aimed at updating and improving the accuracy of these models. Still there is much we do not yet know about these processes. One of the processes which is receiving considerable attention is the phenomena of spacecraft charging and its effect on satellite systems reliability. In this paper, I will describe the phenomena of spacecraft charging and some of the results from the R&D investigation directed at solving the satellite charging problem. In addition, environmental technology gaps which should be investigated prior to development of next generation spacecraft will be discussed. These spacecraft are envisioned to be physically large in dimensions, to use high operating power levels, and to perform in space as computers. Because of these system characteristics, new physical processes in the environment will likely become important in systems engineering.

BACKGROUND

In 1969, scientific data from NASA's ATS-5 satellite suggested that on occasion the vehicle was charged negatively to thousands of volts by the space plasma environment.[1]

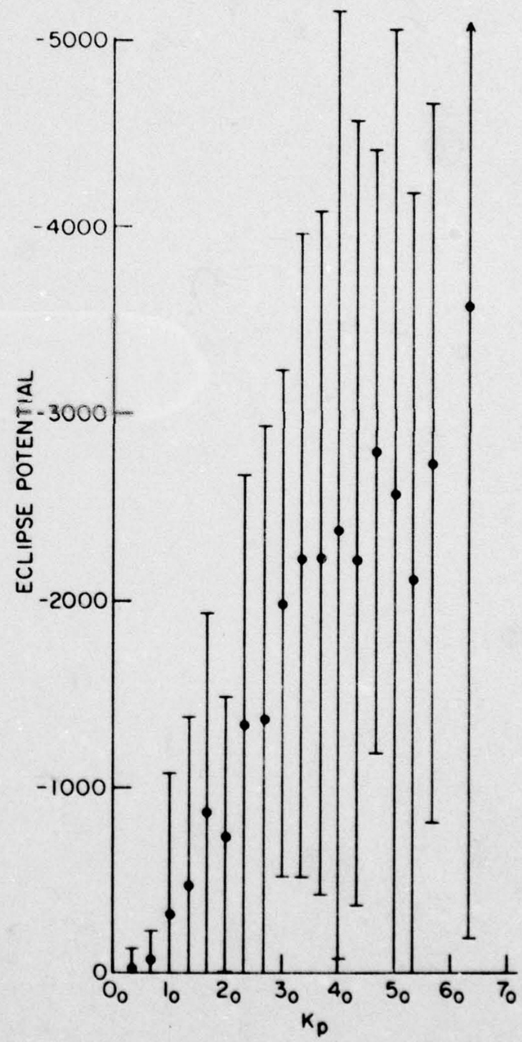

Fig. 1. Average eclipse potentials observed on ATS-5 (1969-1972) and on ATS-6 (1976) are plotted versus K_p, the geomagnetic activity index.

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The ATS-5 particle spectra revealed that the low energy positive ion (electron) population is accelerated if the satellite is negatively (positively)charged with respect to the ambient plasma. This produced a sharp cutoff in the particle spectra immediately below the energy channel corresponding to the satellite's potential. Figure 1, derived from the ATS-5 particle spectra, is a plot of inferred ATS-5 voltages, recorded during eclipse, versus K_p, the geomagnetic activity index.[2] From Figure 1, the eclipse potential is seen to become increasingly negative as geomagnetic activity increases.

In 1971, Air Force satellites operating at geosynchronous altitudes began to display operating anomalies which included:[3] gain control logic switching, thermal control degradation, sensor data noise, erroneous operation of attitude control switching, and power systems failure. Since that time, many hundreds of operating anomalies have occurred, and some of these are very likely due to the environment. In 1976, harness noise detectors were flown on the Communications Technology Satellite and, in 1978, on the Orbital Test Satellite to look for the occurrence of voltage transients produced by spacecraft discharges.[4] The occurrence of transients in spacecraft harnesses appears to occur randomly in local time. The existence of multiple pulse transients in the harnesses indicates that discharges on spacecraft may often take the form of many small discharges rather than a single, large discharge.

THE PROBLEM

The phenomena of spacecraft charging involves the complex interaction between a satellite and the space plasma environment. Figure 2 depicts this interaction. During a magnetospheric substorm, the ambient electron and ion temperature at geosynchronous altitudes increase by about a factor

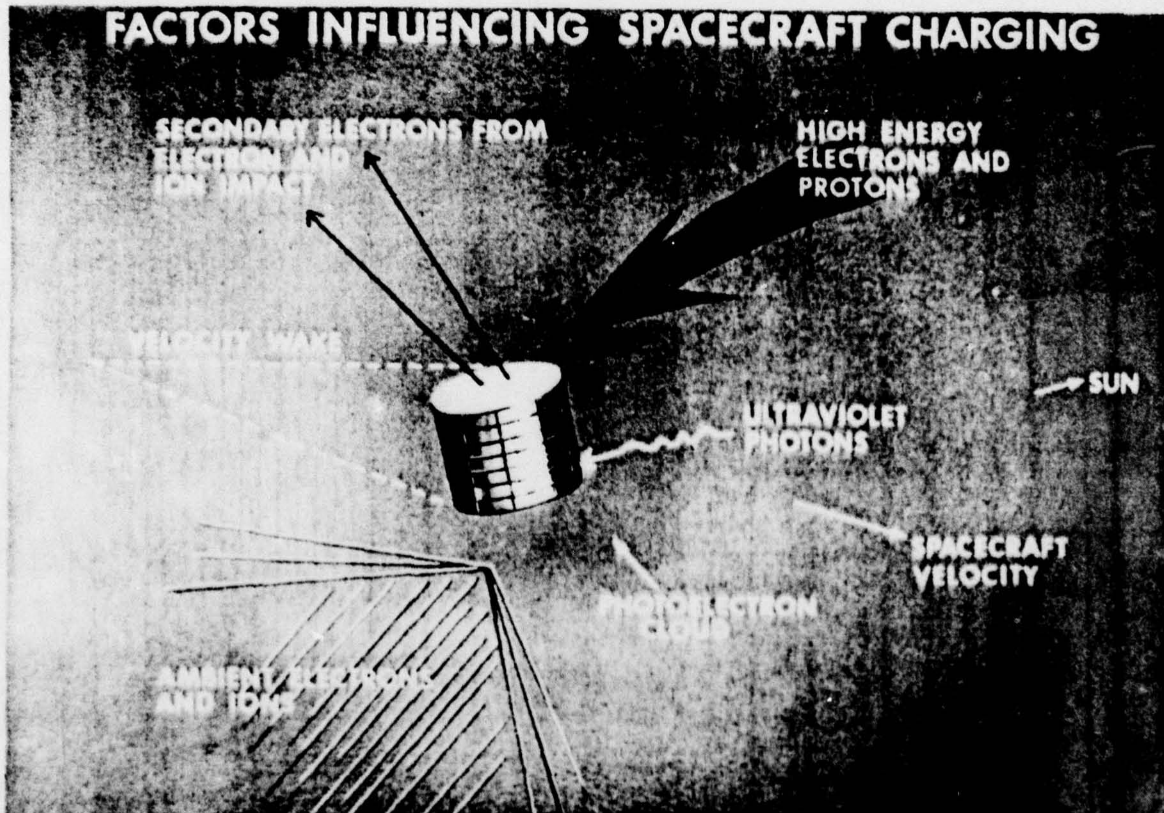

Fig. 2. The factors which influence the absolute and differential charging of a spacecraft are shown schematically.

of 4 for periods of 1 to 2 hours. When substorms occur, satellites, wrapped in their thermal insulation blanket, become essentially capacitors immersed in a high temperature plasma. Secondary emission from electrons and ions, photoelectron emission, and the ambient thermal plasma all contribute to the satellite's net potential. Anisotropies in the plasma sheath, created by spin, velocity, and shadowing, complicate the interaction and influence the charge balance. Shadowing of the spacecraft by the sun allows a high negative differential potential to develop between the dark side of the spacecraft and the sunlit side which has a potential near zero. When sufficient voltage stresses occur, current discharges can follow which produce electromagnetic interference (EMI). The EMI could cause the circuit upsets that have been observed.

Regions in the earth's magnetosphere in which spacecraft charging is likely to occur are shaded in Figure 3. These regions include the plasmasheet, located on the nightside of the earth in the earth's magnetic tail, and the polar cusp, located on the dayside of the earth. The polar cusp is the region through which thermalized solar wind plasma penetrates down to the 100 km height level near the magnetic poles of the earth. The plasma sheet region on the nightside of the earth is the operating environment for geosynchronous satellites for about 12 hours each day. Most of the operating anomalies experienced by satellites, that may be attributed to spacecraft charging, have occurred when spacecraft were in the plasmasheet.

AFSC/NASA SPACECRAFT CHARGING INVESTIGATION

Technology involving spacecraft charging is one of the many interdependent research areas in aeronautics and astronautics that are coordinated by the Air Force Systems Command (AFSC) and NASA Space Research and Technology Review Group. NASA and DOD strive to identify these common technical problems

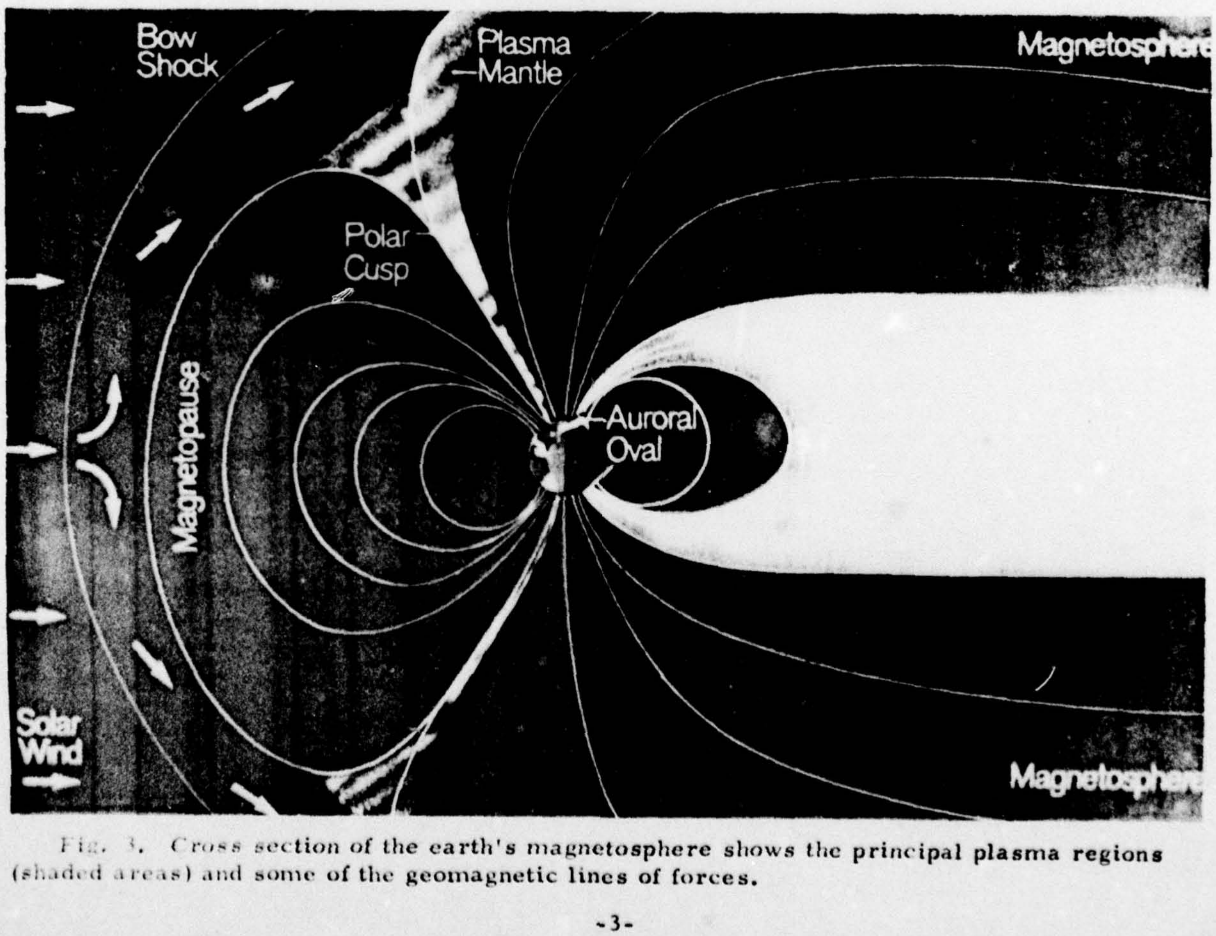

Fig. 3. Cross section of the earth's magnetosphere shows the principal plasma regions (shaded areas) and some of the geomagnetic lines of forces.

and then assign agency responsibility for providing the required technology. Spacecraft charging is a five year investigation between AFSC's Director of Laboratories and NASA's Office of Aeronautics and Space Technology. A steering committee incorporates NASA and DOD requirements into the investigation. Each technology element of the investigation is assigned to either NASA or the Air Force with well defined accountability. Contractual and in-house efforts are working on this investigation. The goal of the spacecraft charging technology investigation is to protect our satellites from the harmful effects of high voltage arc discharges. The objectives of the investigation are to develop the design criteria, techniques, and test methods to ensure control of absolute and differential charging of spacecraft surfaces. Technology elements of the investigation include: 1) a definition and specification of the space environment which induces the charging; 2) the development of analytical tools to model the interactions between the environment and the spacecraft surfaces; 3) the development of ground facilities to conduct materials and systems evaluations; 4) the development of new or modified spacecraft materials for charge control; and 5) the analysis and interpretation of flight data in order to validate results of the analytical tools and to calibrate ground facilities. The status of the spacecraft charging technology base will be summarized in the next sections of the paper.

Environmental Model

At the Air Force Geophysics Laboratory, a statistical model of the geosynchronous plasma environment[2,5] has been developed from data recorded by the University of California at San Diego plasma experiment on the ATS-5 and 6 satellites. The ATS-5 and 6 data consists of differential count rates as a function of time. The count rates were converted to differential flux spectra from which the temperature and currents were determined. The environmental model has been developed so that it could be applied to calculations of spacecraft potential.

Data analysis indicated that the geosynchronous plasma environment is, at the very least, composed of a two component Maxwellian plasma. In the environmental model, the plasma distribution is assumed to be Maxwellian and isotropic. This was done to reduce the number of parameters required to characterize the plasma. For a Maxwellian particle distribution, the four moments of the distribution function are:

$\langle N_i \rangle$ = number density for species i (number/cm^3)

$\langle NF_i \rangle$ = number flux for species i (number/cm^2 sec-sr)

$\langle EN_i \rangle$ = energy density for species i (ev/cm^3)

$\langle EF_i \rangle$ = energy flux for species i (ev/cm^2 sec-sr)

In Figure 4 the actual electron distribution function, the Maxwellian fit, and the two Maxwellian fit are plotted. Neither exactly fits the distribution function but, of the two approximations, the two Maxwellian fit gives a much better representation of the actual distribution function.

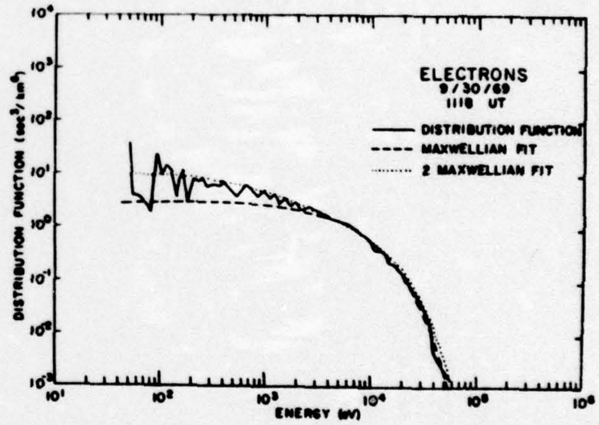

Fig. 4. Actual Maxwellian fit and 2 Maxwellian fit distribution functions for electrons measured from ATS-5.

For a single Maxwellian plasma, the temperature T(AVG) and T(RMS) are equal.

That is:

$$T_i\,(AVG) = \frac{2}{3}\,\frac{\langle EN_i \rangle}{\langle N_i \rangle} = T_i \qquad (1)$$

$$T_i\,(RMS) = \frac{1}{2}\,\frac{\langle EF_i \rangle}{\langle NF_i \rangle} = T_i \qquad (2)$$

$$T_i\,(AVG) = T_i\,(RMS) \qquad (3)$$

If, however, the plasma consists of two or more components such as found at geosynchronous orbit, then:

$$T_i\ (AVG) = \frac{2}{3}\frac{\langle EN_i \rangle}{\langle N_i \rangle} \tag{4}$$

$$= \frac{N_{1i}\ T_{1i} + N_{2i}\ T_{2i}}{N_{1i} + N_{2i}}$$

$$T_i\ (RMS) = \frac{1}{2}\frac{\langle EF_i \rangle}{\langle NF_i \rangle} \tag{5}$$

$$= \frac{N_{1i}\ T_{1i}^{3/2} + N_{2i}\ T_{2i}^{3/2}}{N_{1i}\ T_{1i}^{1/2} + N_{2i}\ T_{2i}^{1/2}}$$

So that in general:

$$T_i\ (AVG) \neq T_i\ (RMS) \tag{6}$$

This represents a serious dilemma in defining the temperature. A definition in terms of N_1, N_2, T_1, and T_2 is to be preferred over T(AVG) and T(RMS. Technically, T(AVG) is the preferred definition if a single temperature is desired. For use in spacecraft potential calculation, it does not necessarily give the best estimate of the potential for which T(RMS) may be the more conservative estimate. Their difference is a measure of the deviation of the plasma from a single Maxwellian. Although T(AVG) and T(RMS) do not provide an accurate description of the plasma, they are one approach to defining the environment.

The current to the spacecraft (actually the current per unit area) is the other quantity most often required for potental calculations. The current, J_i, can be derived directly from the 4 moments.[5]

$$J_i = q_i \int_0^{\infty} \vec{V}_i \cdot \vec{n}\ f\ d^3 V = \tag{7}$$

$$= \pi\ q_i \langle NF_i \rangle \tag{8}$$

where

$\vec{n}$ = unit normal to area

q_i = charge on species (coulombs)

J_i = current per unit area (amps/cm^2)

This assumes the particle flux to be omnidirectional. If, as is observed on occasion, the plasma flux is directional, then the integral of equation 7 would not be $\pi\ q \langle NF_i \rangle$ (observations indicate a correction factor on the order of unity) - a factor that should be taken into account in considering these results.

For the environmental model, the ATS-5 and 6 differential energy flux has been integrated to give the four moments which were averaged over 10 minute intervals. The ATS-5 data for the parallel and perpendicular detectors were averaged together. This data base of approximately 50 days of ATS-5 and ATS-6 plasma data form the model. T(AVG) and T(RMS) were calculated from these data.

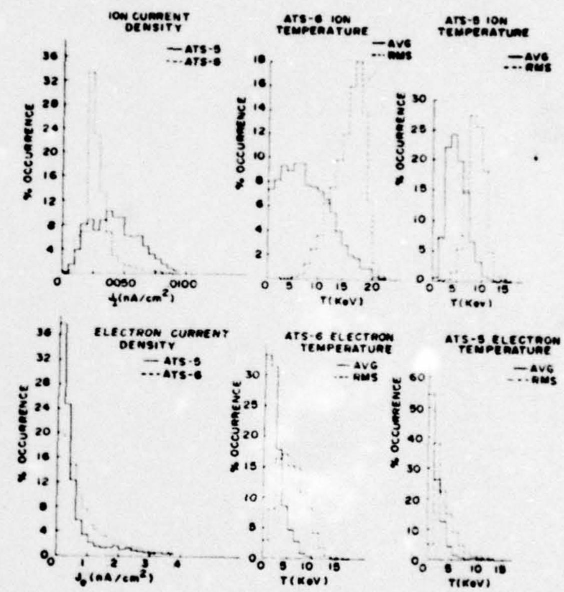

Fig. 5. Statistics of the ATS-5 and 6 electron and ion temperature and the current density.

Figure 5 shows the occurrence frequencies of various values of T(AVG), T(RMS), and current for electrons and ions from ATS-5 and ATS-6. The distributions in Figure 5 can be described in terms of standard statistical distributions for data randomly distributed around some mean (i.e., either a Poisson or Gaussian distribution). Table 1 lists approximate averages and standard deviations for each distribution.

The most significant feature of Figure 5 is the approximate factor of 2 increase between T(AVG) and T(RMS). This can be interpreted

	T(AVG) in eV	T(RMS) in eV	J in n A/cm^2
Electrons ATS-5	1500*	3480 $\pm$ 2070	.045*
ATS-6	2290 $\pm$ 1800	5640 $\pm$ 2700	.08*
Ions ATS-5	5030 $\pm$ 2010	8750 $\pm$ 1860	0.0043 $\pm$ 0.0021
ATS-6	7880 $\pm$ 4900	16000 $\pm$ 3400	0.0026 $\pm$ 0.0012

* Based on an exponential probability distribution where $P(x) = \frac{1}{B} e^{-X/B}$, B given in Table.

Table 1. Average and Standard Deviations for T(AVG), T(RMS), and the Current for the Geosynchronous Electron and Ion Plasma Populations Measured by ATS-5 and ATS-6. The ATS-6 data are provisional.

in terms of T_1 and T_2 if we assume the plasma to consist of two separate components. ATS-5 mean values of N_1, T_1, N_2, and T_2 for the electrons and ions were put into Equations 4 and 5 to calculate T(AVG) and T(RMS):

$$e^-: \left.\begin{array}{l} N_1 = 0.83/cm^3 \\ T_1 = 500 \text{ eV} \\ N_2 = 0.17/cm^2 \\ T_2 = 6000 \text{ eV} \end{array}\right\} \begin{array}{l} T(AVG) = 1435 \text{ eV} \\ T(RMS) = 2780 \text{ eV} \end{array}$$

$$I^+: \left.\begin{array}{l} N_1 = 0.5/cm^3 \\ T_1 = 100 \text{ eV} \\ N_2 = 0.5/cm^3 \\ T_2 = 9000 \text{ eV} \end{array}\right\} \begin{array}{l} T(AVG) = 4550 \text{ eV} \\ T(RMS) = 8150 \text{ eV} \end{array}$$

These results are in agreement with Table 1 and offer a clear example of the effect that two or more plasma populations have in limiting the usefulness of a definition of the plasma in terms of a single Maxwellian distribution. Another obvious feature is the near-doubling of the electron and ion temperatures from 1969 and 1970 (ATS-5 data) to 1974 and 1976 (ATS-6 data). The electron current also doubles while the ion current actually decreases between ATS-5 and ATS-6. It is not possible to say with certainty how much of this effect is due to orbital differences between ATS-5 and ATS-6. It appears likely, however, that a change in geomagnetic activity between the ATS-5 and ATS-6 data is the primary cause.

NASCAP: A Satellite Charging Analyzer Program

A theoretical description of the process of spacecraft charging by magnetospheric substorm plasmas has been prepared in the form of a computer code called NASCAP[6] (NASA Charging Analyzer Program). NASCAP was developed by Systems, Science and Software, Inc. under NASA and Air Force sponsorship. The NASCAP code was developed to compute from Poisson's equation the voltage distributions on and around spacecraft due to the charging environment. The NASCAP code performs a dynamic, fully three-dimensional simulation of electrostatic charging processes for an object in space or in a ground test chamber environment. In particular, the code predicts surface potentials on spacecraft; identifies high-field areas of possible discharge sites; predicts response to environmental charge; predicts and interprets particle detector response and assesses the effects of particle emission from active control devices. In the code the spacecraft is represented by a finite element method, each element being a cube or a slice of a cube. Figure 6 shows the SCATHA satellite as represented by the code. The computations are performed in nested meshes, with an inner mesh size of 16x16x32 cells. Each successive mesh has double the mesh spacing, and as many as seven meshes have been employed. A different material may be specified for each element surface, so that properties such as secondary emission, backscattering, photoemission and conductivity may be taken into account for each cell. Figure 6 is an illustration of material specification for the SCATHA satellite surface, showing how detailed a representation for different materials can be obtained. The surface resolution of spacecraft detail is about 10 cm. Figure 7 shows a calculation of potential con-

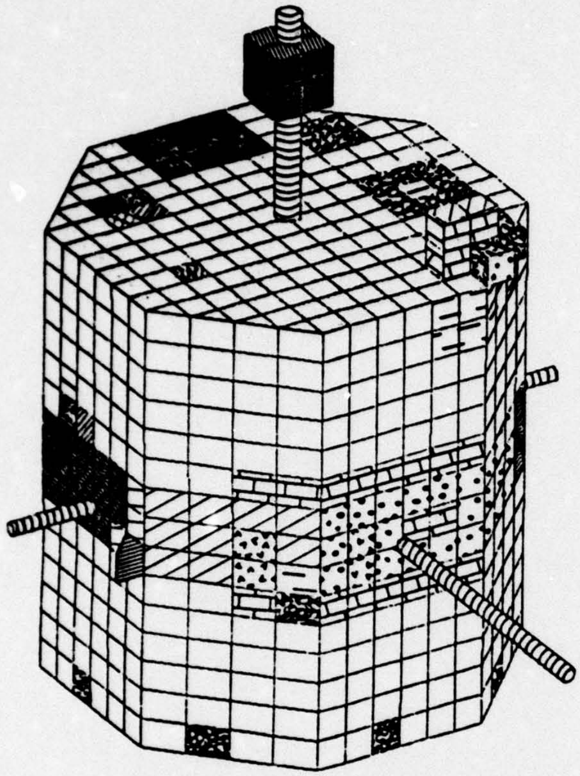

Fig. 6. Cells with different materials for the SCATHA satellite. Booms are shown on the sides and the telemetry antenna is shown on the top of SCATHA.

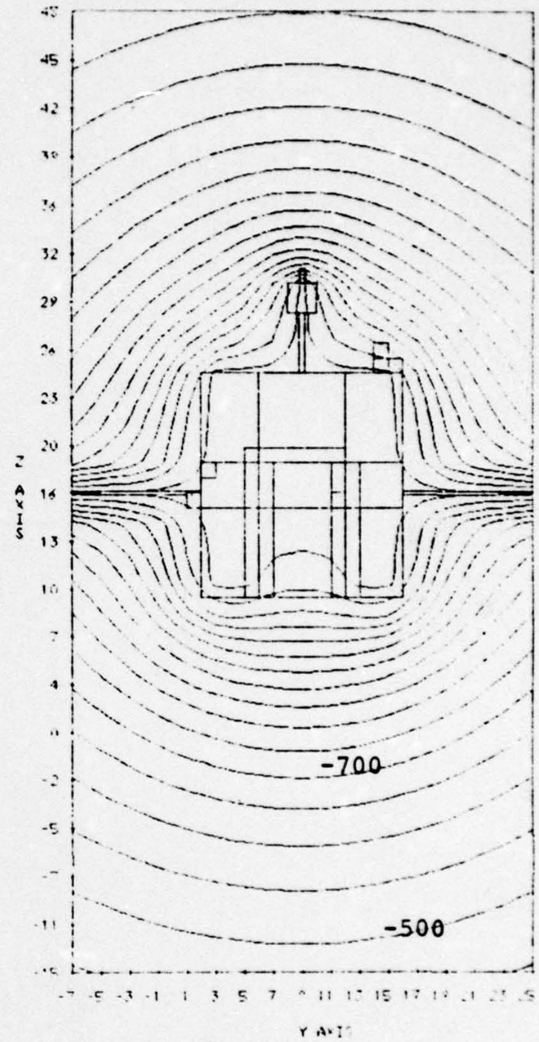

Fig. 7. Potential contours in volts calculated for the SCATHA satellite from NASCAP.

tours in a vertical plane through the center of SCATHA at 1 millisecond after the start of a substorm. The code calculates particle trajectories in these sheath fields as well. The NASCAP application to SCATHA has resulted in the most advanced satellite charging code available. It will be extensively employed in the analysis of spacecraft charging and active control of satellite systems, for studies of contamination, and for the analysis of the response of particle detectors on mission and scientific spacecraft (see Figure 8).

Simulation Facilities

At NASA Lewis Research Center, simulation facilities have been developed to determine the charging and discharging characteristics of insulators subjected to substorm fluxes.[7] The charging characteristics of a wide variety of insulators have been catalogued. The discharge characteristics are currently being evaluated with the goal of determining the discharge threshold and energy content for various insulator areas and configurations. These studies will continue to build toward a spacecraft size configuration for comparison with flight results. The ground simulation facilities have been used to obtain data to support projects such as SCATHA, TDRSS, Jupiter Orbiter Probe, and LDEF experiments.

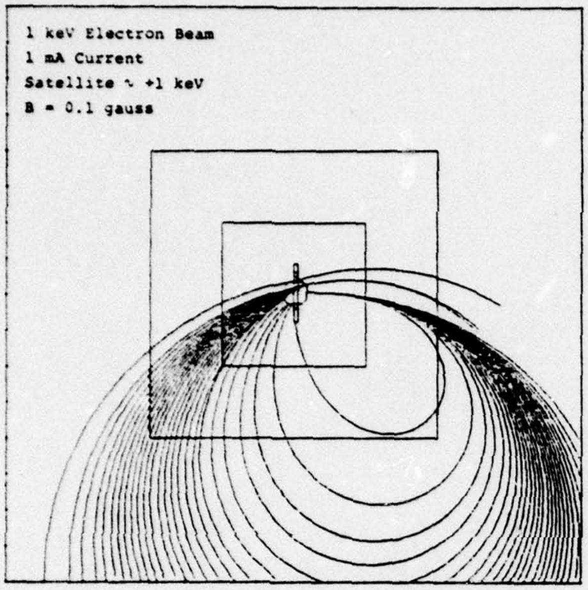

Fig. 8. NASCAP calculation of an electron beam, emitted from SCATHA, impinging back on the spacecraft.

Materials Development

The space stable silica fabric type thermal control coatings developed under AF Materials Laboratory sponsorship have been found to display an inherently low susceptibility to charging in the synchronous orbit environment. These materials are finding application on DSCS III.

Thin, stable transparent conductive antistatic spacecraft charging control coatings have been developed suitable for application to the thermal blankets, second surface mirrors, solar cell covers and other dielectric materials found on the exterior surfaces of spacecraft. These thin indium and indium-tin oxide coatings are applied using vacuum deposition techniques. The coatings are stable in the synchronous orbit environment. Coating optimization and development of stable grounding techniques are now underway.

Electric Fields Within Dielectrics

The Rome Air Development Center, Deputy for Electronics Technology and the AF Weapons Laboratory are investigating charge buildup in dielectrics. Space radiation is of high enough energy to penetrate to significant depths within dielectrics, several millimeters in some situations; under these conditions we can use macroscopic material properties to calculate the internal fields and currents in dielectrics. The important macroscopic properties include photoconductivity, radiation transport, radiation induced conductivity, dark conductivity, dielectric constant, field dependent conductivity, secondary emission and field induced breakdown. It turns out that bulk macroscopic fields are likely to exceed 10^5 V/cm (by as much as two orders of magnitude) in many good dielectrics under electron or photon irradiation above 10 keV per quanta.

Calculations[8,9] and experiments[10,11,12] indicate that the probability for the bulk electric field exceeding breakdown potential is strongly dependent on each one of the properties. A slight change in the irradiation spectra, in dielectrics properties, or in the dielectric geometry can strongly influence the electric field magnitude. The temporal history of the irradiation spectra may also be important. In any case, large fields will almost always be present within most spaceborne dielectrics and the possibility of spontaneous discharge or externally triggered dielectric discharge is large.

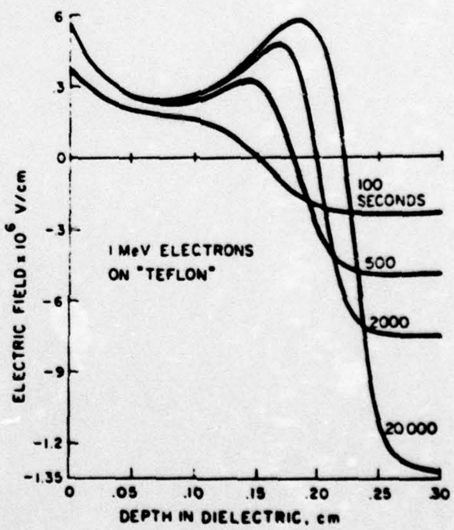

Fig. 9. Electric fields in teflon after various irradiation times by 10^{-9} amps cm^{-2}.

An example of calculated electric fields is shown in Figure 9. These fields are caused by electron irradiation of a .3 cm thick sheet of teflon, initially field free, by a continuous broad beam of electrons beginning at zero seconds. Lower energy electrons create similar effects, but their space charge fields are large over smaller depths.

At the Air Force Weapons Laboratory, a program is directed at investigating the effects of a systems generated electromagnetic pulse on an electrically charged satellite. Another investigates the charge buildup on a satellite, which occurs after a high altitude detonation, and the charge breakdown processes.

SCATHA

The SCATHA (Spacecraft Charging at High Altitudes) satellite (see Figure 10) is an integrated satellite experiment that is being used to measure the characteristics of the spacecraft charging phenomenon, to determine the response of the satellite to the charging process, and to evaluate corrective techniques. The SCATHA satellite is part of the Space Test Program manged by SAMSO.[13] Martin Marietta was the prime spacecaft contractor. Launch was on a DELTA 2914 from the Eastern Test Range on 30 January 1979. SCATHA has an equatorial orbit with an apogee of 7.7 earth radii and perigee of 5.5 earth radii and drifts easterly at 6 degree/day.

The thirteen experiments on SCATHA (see Table 2) are provided by Air Force, Navy, NASA, Defense Nuclear Agency, industry and university groups. There are engineering experiments to measure surface potentials and the electrical effects of spacecraft charging on satellite surface and subsystems. Environmental experiments will measure the characteristic fields and particle fluxes. An electron beam system and a positive beam system are being used to develop techniques to actively control spacecraft charging. The engineering, environmental and charge control experiments were selected to work in concert and, thus, relate cause and effect in spacecraft charging.

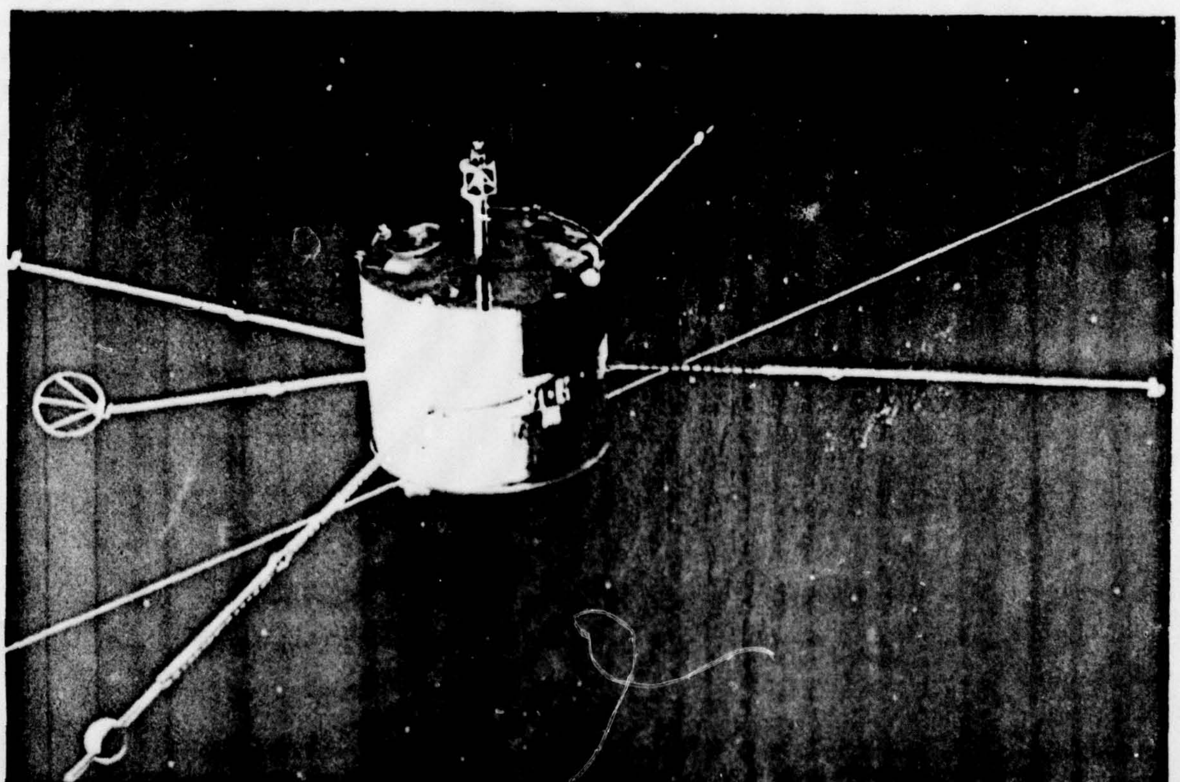

Fig. 10. SCATHA satellite.

Experiment Number	Title	Principal Investigator/ Sponsor	Address
SC1	Engineering Experiments	Dr. H. C. Koons/ USAF/AFSC/SAMSO	The Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009
SC2	Spacecraft Sheath Electric Fields	Dr. J. F. Fennell/ USAF/AFSC/SAMSO	The Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009
SC3	High Energy Particle Spectrometer	Dr. J. B. Reagan Office of Naval Research	Lo[illegible]d Palo Alto Research Lab, [illegible]251 Hanover Street Palo Alto, CA 94304
SC4	Satellite Electron and Positive Ion Beam System	Dr. H. A. Cohen/ USAF/AFSC	Hanscom AFB/LKB Bedford, MA 01731
SC5	Rapid Scan Particle Detector	Lt. [illegible] Hardy/ USAF/AFSC	Hanscom AFB/PHE Bedford, MA 01731
SC6	Thermal Plasma Analyser	Dr. R. C. Sagalyn/ USAF/AFSC	Hanscom AFB/PHR Bedford, MA 01731
SC7	Light Ion Mass Spectrometer	Dr. D. L. Reasoner/ Office of Naval Research	NASA Marshall Space Flight Center, Code BS-23 Huntsville, AL 35815
SC8	Energetic Ion Composition Experiment	Dr. R. G. Johnson/ Office of Naval Research	Lockheed Palo Alto Research Lab, 3251 Hanover Street Palo Alto, CA 94304
SC9	UCSD Charged Particle Experiment	Dr. S. E. Deforest/ Office of Naval Research/USAF/AFSC/ SAMSO	University of California B019 Dept. of Physics La Jolla, CA 92093
SC10	Electric Field Detector	Dr. T. L. Aggson/ Office of Naval Research	NASA Goddard Space Flight Center, Code 625 Greenbelt, MD 20771
SC11	Magnetic Field Monitor	Dr. B. G. Ledley/ Office of Naval Research	NASA Goddard Space Flight Center, Code 625 Greenbelt, MD 20771
ML12	Spacecraft Contamination	Dr. D. F. Hall/ USAF/AFSC/AFML	The Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009

Table 2. Principal Investigators/Sponsors

Satellite Design Guidelines and Test Specification

NASA Lewis Research Center, in conjunction with Science Applications Inc. has completed a comprehensive review of spacecraft charging investigations.[14,15] This information is assembled into a design guidelines monograph. It summarizes the current state of knowledge of the techniques that should be incorporated to minimize spacecraft charging effects, our knowledge of the charging environment, and the status of analytic modeling of charging.

The Air Force's Space and Missile Systems Organization and Science Applications Inc. have prepared the baseline document for a Spacecraft Charging Military Standard.[16] This document contains details of a spacecraft charging protection program including electrical systems, materials, and contamination; systems analysis requirements; and systems test requirements. This baseline document will be formalized into a Military Standard after completion of the analysis and interpretation of the SCATHA data.

SPACECRAFT ENVIRONMENT INTERACTIONS TECHNOLOGY

A new interdependent technology program between the Air Force and NASA is just beginning. The program will address the interactions between space system and the space environment in which they operate. Program emphasis will be to develop technology supporting space systems that will be composed of large dimension satellites which operate at high power levels. The geophysical environment, including the upper atmosphere and space, is recognized as a significant component in the development and operation of satellite systems. Gaps exist, however, in the environmental technology base that will be required to support the RDT&E of these new systems. These technology gaps include knowledge of the physical mechanisms which regulate the coupling between the environment and the spacecraft; also, knowledge of the extent to which the environment is impacted by the operation of these spacecraft. Research and development, addressing these technology gaps, is an important new direction for environmental technology programs.

With the availability of the Space Transportation System, future mission satellites will likely utilize high power, be structurally complex, and perform as computers in space. The space environment could affect these satellites by limiting the application of on-orbit construction techniques, and the use of large space structures; by limiting the power levels obtained from solar arrays; and by limiting the power levels used in radar and communications amplifier tubes. A related problem area will be to identify the extent to which the space environment itself could be modified by the on-orbit operation of these large space structures. Specifically, we need to assess to what extent the natural particle and field environment could be modified as a large-dimension satellite, employing high power, orbits the earth. (This latter problem area is the space equivalent of an environmental impact assessment). Both of these problem areas will require major extensions of the present state of knowledge of the magnetospheric plasma, particle and field environment including various plasma, particle, and field models. Both low earth orbit (LEO) and geosynchronous earth orbit (GEO) situations must be studied in order to construct space environment models as the basis for identifying, defining, and physically characterizing the various processes and coupling mechanisms by which the space environment could act to limit on-orbit deployment, operability, reliability, and survivability of large structures in space.

A prime motivation for the initiation of this new interdependent technology program is to avoid a repeat of the "spacecraft charging technology gap." The problem of spacecraft charging was unexpected and was only recognized after numerous satellites were experiencing anomalies while stationed on orbit. Once the charging problem was recognized, then an intensive R&D program was initiated. The lead time required for generating spacecraft charging technology is many years. Interim engineering fixes for spacecraft charging have only been partially successful. In FY81, final results of the AFSC/NASA Spacecraft Charging Technology Program and the SCATHA spaceflight will be available for application by the aerospace industry. This is a full 10 years after the problem of spacecraft charging first appeared. The Spacecraft Environment Interactions Technology Program will develop the new technology that will support the Air Force's and NASA's full and cost effective utilization of the Space Transportation System.

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